Clean Water – Clean Environment – 21st Century

Team Agriculture – Working to Protect Water Resources

Conference Proceedings

Volume I: Pesticides

March 5-8, 1995
Kansas City, Missouri

Published by ASAE
2950 Niles Road., St. Joseph, Michigan 49085-9659 USA

Weed Emergence Modeling for a Bioeconomic Weed/Crop Management Expert System

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Summary

Models are being developed that simulate seed dormancy and seedling emergence for weed species important to the Corn Belt. These models permit accurate prediction of weed densities on a daily basis in crops. The models can be used as submodels in larger Bioeconomic Weed/Crop Management Decision Aids prior to crop planting or during crop development to improve the process by which weed control decisions are made. Use of such models in field tests resulted in substantial reductions in herbicide use and large decreases in weed control costs compared to standard farming practices. These models also were used to simulate weed control costs in sections of fields to explore the economic feasibility of site-specific weed management. Modest increases in profit were associated with site-specific weed management recommendations.

Project Description

Modern agriculture relies primarily on herbicides for weed control. These chemicals often are applied at times of the year when weeds are not visible (preplant incorporated and preemergence applications) as insurance against the possibility of a yield-reducing weed infestation. Herbicides applied at these times have a higher probability of entering groundwater and surface waters than herbicides applied after weeds emerge (postemergence herbicides). Postemergence herbicides are applied only when weeds are visible and, therefore, are actually present in the crop. Even with this latter and more objective category of herbicide, however, it typically is applied if a weed is present in a field rather than if the weed is present at a density that reduces crop yields (Swinton et al., 1994). Consequently, the lack of objective decision rules for applying herbicides contributes to their overapplication and eventual contamination of water supplies.

Bioeconomic weed/crop management decision aids (Swinton and King, 1994), or BWMs, make weed management recommendations that reduce herbicide use and the cost of weed control (Forcella et al., 1993a). These reductions occur because model recommendations are based upon objective biological, ecological, and economic information. Necessary biological and ecological information includes 1) the number of weed seeds in a field's soil prior to planting a crop, 2) the proportion of those seeds that will germinate and emerge before the crop is planted, 3) the number of weeds that emerge after the crop is planted, 4) the proportion of weeds that are killed by various control methods (mechanical and chemical), 5) crop yield loss due to the density of weeds that escaped control, 6) the number of seeds produced by weeds that escape control, and 7) the proportion of weed seeds in the soil that survive over winter.

BWMs combine and integrate this information with that of the costs of different types of weed control, other management costs, and the costs of yield loss due to weeds. Yield loss due to weeds is calculated not only for the current year, but also for future years due to the numbers of weed seeds estimated to be produced as a consequence of the current year's management options. The current year's management options are then ranked according to the expected profit over multiple years. The top-ranked management option is not the recommendation that will kill the most weeds. Nor is it necessarily the cheapest recommendation that will provide acceptable yields for the current year but increase the weed seed reserve in the soil to discouragingly high levels. Instead, BWMs "optimize" the current year's management recommendations so that profits are maximized over the long term. Such objective management advice not only has been found to increase profits, but also to reduce herbicide use by more than two-thirds when compared to standard farming practices in the Corn Belt (Forcella et al., 1993a). Although we now know that BWMs can be highly successful in reducing management costs and herbicide use, important limitations remain with these decision aids.

Results

One of the primary limitations of BWMs is the lack of understanding of the basic biology and ecology of important weed species, especially the degree and timing of weed seedling emergence. Our objective in the Weed Emergence Modeling project is to integrate and simulate environmental effects on seed germination and initial seedling elongation so that these events can be predicted on a daily basis. The ultimate goal is to use these simulations in BWMs so that weed control recommendations can be based on objective and accurate estimates of the extent and timing of weed emergence. This objective has been accomplished for several weed species important to the Corn Belt of North America. However, similar information for several other weed species remains to be generated. Because weed infestations usually do not occur as monocultures, but as wide mixtures of species, generating such information for all important weed species is crucial. Long-term goals of the Weed Emergence Modeling project are to develop computer software that permits users to simulate emergence of the weed species of choice based on simple daily weather variables. The weather variables can be supplied by the user for real-time simulation at specific sites, or they can be generated by the software for generalized regions and weather patterns.

In the remainder of this report we will profile examples of progress for select weed species studied during the Weed Emergence Modeling project. Also, we will show how this information can be used to help make objective weed management recommendations that reduce herbicide use and lower weed control costs while potentially increasing on-farm profits.

Examples of empirical dormancy models for two typical species: Nondormant seedbank densities, cumulative seedling densities, and PE (percent emergence) were studied for five years (1990-1994) for monocultures of redroot pigweed and giant foxtail (and many other weed species) in the Weed Nursery at the University of Minnesota's Rosemount Experiment Station. PE is the percent of the seedbank that emerges as seedlings over the course of a single growing season. Each year soil cores were extracted in late March or early April, well in advance of seed germination, to determine the densities of nondormant seeds. These values were estimated using four cycles of the "greenhouse seedbank" method (Forcella, 1992, 1993b). In the field, seedlings of each species were counted and removed from permanently marked areas at weekly intervals throughout the spring and summer. PE was calculated and compared with daily microclimate data. Average annual PE was the same for both species (26%). However, the yearly variation surrounding these values was much different between the species. For instance, PE varied among years from 20% to 32% for giant foxtail, whereas PE for redroot pigweed varied much more, from 9% to 58%. The level of yearly variation can be summarized by an index known as the coefficient of variation, or CV. The CV for giant foxtail was quite low, 16%, whereas that for redroot pigweed was very large, 74%. This variation in yearly PE was related to growing season microclimate in a highly dynamic manner.

After winter stratification, nondormant seeds of pigweed were induced into a state of secondary dormancy when soil water stress levels (0 to 4-inch depth) first fell below 10 bars (atmospheric pressure). Any seed that had not germinated by the time soil water stress fell below 10 bars became dormant. The duration of soil water stress (below 10 bars) necessary to induce secondary dormancy appeared to be less than one day. In contrast, high soil temperatures appeared to induce secondary dormancy in giant foxtail, and 63° F (at 4-inch depth) appeared to be the threshold temperature for inducing nondormant seed into secondary dormancy. The duration of soil temperature at 4 inches greater than 63° F necessary to induce secondary dormancy appeared to be less than one day. Because soil temperatures exceeding 63° F at 4-inch depths occur both later in the year and much less frequently that soil water stresses at or below 10 bars, giant foxtail typically experiences little annual variation in PE relative to that of redroot pigweed.

This understanding of weather-mediated induction into secondary dormancy can be used in bioeconomic weed management models to improve predictions of potential densities of weeds requiring control in crops (Forcella et al., 1993a; Forcella and Buhler, 1994). Such predictions permit appreciable adjustments in the degree of recommended weed control, and they often lead to reductions in herbicide use and the costs of weed management.

Mechanistic models of the timing of weed emergence: The extent and speed of seed germination of both redroot pigweed and giant foxtail (and many other weed species) were determined in incubators under various combinations of temperature and water stress. This information was then used to develop mechanistic simulation models of the timing of seed germination and seedling emergence under field conditions (Forcella, 1993a; Forcella et al., 1993b; Harvey and Forcella, 1993). These models must be supplied with two primary types of information, daily rainfall and average daily soil temperature, as well as the type of field soil (loam, clay loam, etc.). The models automatically calculate daily soil water stress, percent germination, seedling elongation, and cumulative seedling emergence as a percentage of the total number of seedlings that will eventually emerge. These models have been highly successful in predicting cumulative daily seedling emergence when compared to actual observations of seedling emergence in field settings, not only in Minnesota but elsewhere in the Corn Belt as well (Forcella, 1993a; Forcella et al., 1993b; Harvey and Forcella, 1993).

Models that predict the timing of weed seedling emergence can be used to manage weeds with fewer herbicide inputs. For some species, like redroot pigweed, if seedbed preparation and soybean planting are delayed until the model predicts about 80% pigweed seedling emergence, then no additional weed control is necessary other than standard interrow cultivation, and crop yields are maximized (Forcella et al., 1993b). Furthermore, when emergence models are used in BWMs, weed control recommendations vary as crop planting dates are delayed. For example, as soybean planting date changes from early (May 1), to mid-season (May 15), to late (May 30), BWM recommendations typically change from a combination of two herbicides, to one herbicide plus mechanical control, to only mechanical control, respectively. These changes in recommendations are due entirely to the interaction of seedbed preparation (mechanical or chemical) and the timing of weed seedling emergence. Without weed seedling emergence models, BWMs could not calculate the reduction in weed density due to seedbed preparation. Consequently, BWMs often would overestimate weed densities and recommend unnecessarily high levels of weed control and herbicide use.

Site-specific weed management: Using actual weed population data taken on a 177-foot grid system from commercial fields, we also have explored the use of BWMs in site-specific weed management (Barbour et al., 1994). When relatively clean 160-acre fields are managed as smaller units according to BWM recommendations, profit margins increase by about $4 per acre as opposed to uniform management for the entire field. Profit margins increase as weed densities increase and as weed distributions become increasingly patchy.

Technology Transfer

Transfer of the technology generated by the Weed Emergence Modeling project is ongoing. Not only have the results been presented at professional scientific society meetings, but also to groups of crop consultants who may be the ultimate users of the information. For example, models have been demonstrated at the Minnesota Crop Pest Management Short Course Workshop (Barbour and Forcella, 1993), the North Dakota Crop Consultants Association, and the joint Minnesota/North Dakota Pesticide Workshop. Special workshops also have been organized by the principal investigator for weed scientists at the North Central Weed Science Society Annual Meeting in Indianapolis (1992) and Kansas City (1993). The Weed Emergence Modeling project has been an important component of the NC–202 Regional Research Committee, whose charge is the development of Bioeconomic Weed Management Models.

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